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ENTROPY DYNAMICS ASSOCIATED WITH SELF-ORGANIZATION

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A general model linking dynamics of informational entropy and the self-organization process in an open, steady-state, nonequilibrium system is proposed. Formulas for dynamics of the informational entropy flow and its rate are developed with respect to random process of influences exerted upon a system. It was revealed that the open system responds to a strong change of conditions by steep growth of the informational entropy flow up to a maximum value at the critical point associated with the self-organization process. An example of self-organization during elasto-plastic deformation of metal is considered.

1 Introduction

In this paper, we consider an open, steady-state, nonequilibrium, active system to be a dissipative system. The spectrum of such systems is quite broad. If an exchange of energy and matter with environment is structured, we can designate it as a transfer of information (entropy). In this broad sense, information exchange is not necessarily limited to "intelligent" systems [1]. Presence of an energy flux from an external source to a system and the dissipation of energy on external environment are the preconditions of activity in any system. Because of this, the evolution of open active systems does not necessarily lead towards the equilibrium state. On the contrary, open systems may be involved in processes of self-organization, which result in more complicated and more advanced structures.

As is known [8,9] for open systems the variation of the entropy dS for an interval of time dt can be decomposed into a sum of two components d_eS and d_iS, with quite different physical meanings. d_eS is the entropy flow, which depends on the processes of matter and energy exchange between system and environment. d_iS is the entropy production, caused by irreversible processes inside the system. If conditions $d_eS<0$ and $|d_eS|>d_iS$ are observed, the certain stages of temporal evolution in the open system can occur at a general downturn of entropy $dS<0$.

It is necessary to note that such a situation is possible only far from equilibrium, as in an equilibrium state the member d_iS always prevails. It means that a system is so far from its equilibrium that the linear laws no longer apply; nonlinear terms become important. Self-organization is the "supercritical" phenomenon. Nevertheless far from equilibrium, the system may still evolve to some steady state. In far from equilibrium conditions, various types of self-organization processes may occur.

According to the traditional interpretation of entropy, as a measure of disordering (uncertainty) of a system, it should be considered that, if the disorder decreases at the expense of entropy return in the course of evolution, the system evolves into more complicated and more advanced structures [8].

We present a general model linking dynamics of informational entropy and the self-organization process in an open system. We analyze the local zone's behavior in different "modes of being" [3]. Formulas for dynamics of the entropy flow and its rate are obtained with respect to process of influences exerted upon a system. Finally we describe a few examples in order to elucidate the received results.

2 Definitions and Mathematical Formulation

Let an open system be in a steady (stable), nonequilibrium state. Further, let us assume that in this state the entropy production is compensated for by a negative entropy flow

$$d_iS = -d_eS, \tag{1}$$

i.e., the system gives back so much entropy as is produced inside the system. Eq. (1) establishes a condition of current balance between the entropy flow through the system and its production inside the system. Current balance is understood as a stationary (not time-dependent) nonequilibrium state of an open system, stable in relation to small deviations. The system in this state is actually in dynamic balance with its environment. The entropy production inside the system in a certain sense characterizes exhaustion of the system's lifespan. Formulas, describing dynamics of the entropy flow and its rate, will be deduced below. According to Eq. (1), these terms can be extended to the internal entropy production inside the system in a steady (stable) nonequilibrium state.

All real processes are irreversible and unbalanced in some degree. Local gradients of temperature, chemical potential, pressure can exist only in a nonequilibrium system. Let X be an important local parameter, determining longevity, lifetime, load-carrying capacity or any other property of vital significance for an open system in a local zone (hereafter we call X the *determining parameter*). Further, let us label a zone of an increased gradient of the determining parameter as the *local dissipative zone* (*LDZ*). Such a local zone limits the lifetime of a system. As a rule, these zones correspond to places of the most probable failures during its lifetime. In the course of intensive operating, the number of LDZ can grow. The growth dynamics of the LDZ number is an important property of the behavior of dissipative system; however, in this paper this question is not considered. Here we investigate the evolution of a system based on processes, occurring only in one LDZ.

There are at least two auto-regulating mechanisms of energy dissipation, which act inside a system. We consider the behavior of a LDZ by using the model of a bistable element. A bistable element (Fig. 1) has two stable states (down and up), in each of which it can exist for a rather long time. Let us denote the mean value of the determining parameter of a system in the down state as X_0 and in up state as X_1. External influences or internal changes in a system can result in transition of the bistable element from one state to another. It was assumed that the transition from down state to up state is caused by such an external influence exerted upon a system, at which determining parameter X (the average over a volume of LDZ) exceeds mean value of the threshold level X_{th}.

In each particular case, the physical content of determining parameter, its threshold level and criterion of transition from one state to another are defined by the type and natures of the system examined and depend on the statement of a problem. In Sec. 5 we shall consider interpretation of this concept for elasto-plastic deformation of metal in the local zone of a load-carrying structure.

For studying the behavior of the LDZ of an open system, the mathematical apparatus of Markovian stochastic processes was used. Solution of the differential Kolmogorov equations for the probabilities $P_0(t)$ and $P_1(t)$ of respectively, the down and up states of the bistable element was obtained [11]. The case of a homogeneous Markovian process were considered, that is the transition rates $\mu(t)$ and $\nu(t)$ respectively, from the up state to the down state and vice versa do not depend on time: $\mu(t)=\mu$; $\nu(t)=\nu$. Hereafter we call $\alpha = \nu/\mu$ the *regime parameter*. Depending on the regime parameter, α, three typical "modes of being" [3] the LDZ are considered: light at $\alpha<1$, $\nu<\mu$, $P_0>P_1$, i.e., the LDZ is in

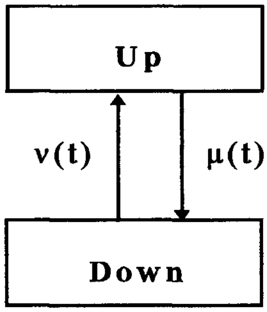

Figure 1. Graph of transition in the bistable element modeling the LDZ behavior.

the down state for a long period of time; symmetric at $\alpha=1$, $\nu=\mu$, $P_0=P_1=0.5$; heavy at $\alpha>1$, $\nu>\mu$, $P_1>P_0$, i.e., the LDZ is in the up state for a long period of time.

3 General Results

Let us consider the behavior of the statistical properties of the determining parameter X for the examined LDZ in the course of evolution. Time dependence of mean value X(t) of the determining parameter was determined under the obtained formula

$$\bar{X}(t)=\left[X_0+\alpha X_1-\alpha(X_1-X_0)e^{-\beta t}\right]/(1+\alpha), \tag{2}$$

where $\beta=\nu+\mu$. At transient stage, the mean value has the tendency to grow or decrease depending on the initial conditions, as shown in Figure 2 by solid line. Curve 1 occurs when the initial state is the down one and curve 2 – when the initial state is the up. The dashed line corresponds to the steady level of the mean value of determining parameter. One can observe that both lines 1 and 2 approached the steady level at stationary stage.

The second of the principal statistical properties we studied is variance of the determining parameter X. The time course of a variance $D_X(t)$ was described by term

$$D_X(t)=(X_1-X_0)^2\left[P_0(t)-P_0^2(t)\right]. \tag{3}$$

The graph of time courses of the variance $D_x(t)$ for heavy and light modes of the system being is shown in Figure 3. Since in the initial moment of time $P_0(t_0)=1$, we have $D_X(t_0)=0$. At the stationary stage (at $t\to\infty$) we have

$$D_{ST} = (X_1 - X_0)^2 \frac{\alpha}{(1+\alpha)^2}. \tag{4}$$

For heavy mode of being at $\alpha>1$ in a critical point, corresponding to a moment

$$t_b = -\frac{1}{\beta}\ln\left(\frac{\alpha-1}{2\alpha}\right) \tag{5}$$

the function (3) has a maximum. The light mode of the LDZ being when $\alpha<1$ (See line 2 in Figure 3) is characterized by absence of the critical point and by stabilization of the variance on the level D_{ST} in the course of evolution towards a stationary stable state.

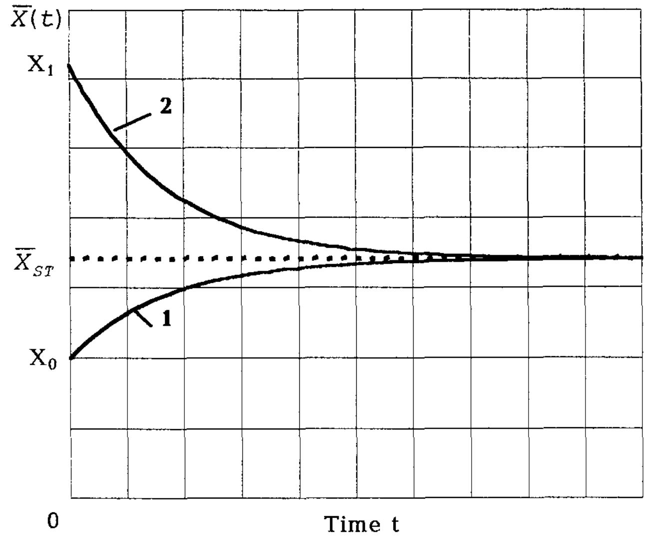

Figure 2. The time courses of the mean value of determining parameter (solid lines) from down (1) and up (2) initial states. Steady level is denoted by a dashed line.

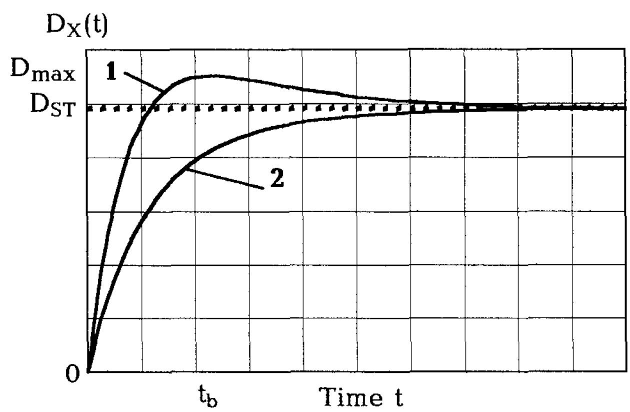

Figure 3. The time courses of the variance $D_X(t)$ for heavy (1) and light (2) modes of being (solid lines). Steady level D_{ST} is denoted by a dashed line. The coordinates of the critical point are labeled as D_{max} and t_b.

Let us assume that the random process Y(t) of dynamic influences with probability distribution function (PDF) F(Y), is exerted upon a system. This process produces a similar random process X(t) of changing the determining parameter X in the LDZ. Further, let us assume the PDF for instantaneous values of the random process is F(X). A dependence of regime parameter α on the PDF of this process is obtained in the form

$$F(X_{th}) = P_0 = 1/(1+\alpha),\ \ 1 - F(X_{th}) = P_1 = \alpha/(1+\alpha), \tag{6}$$

where $F(X_{th})$ is the value of PDF F(X) at the threshold level of X_{th}, P_0 and P_1 are final probabilities of the down and up states corresponding to the stationary stage. In Sec. 5 we shall obtain functions connecting regime parameter α and statistical properties (mean value and variance) of normal (Gaussian) random process exerted upon a system.

The main point of interest of the foregoing analysis is the possibility of computing and forecasting the time course of entropy. Note that various interpretations of entropy are internally linked quite closely [7,8]. The physical entropy of a system coincides with the thermodynamic entropy S. The informational entropy H is connected to them by a ratio [7]:

$$S = kH \ln 2, \tag{7}$$

where k is the Bolzmann constant. We consider the informational entropy, being the measure of uncertainty, and equal to the amount of information (according to Shannon) required for removing this uncertainty. For the bistable element modelling the LDZ, the informational entropy H is determined from the equation [7]:

$$H = -\sum_{j=0}^{1} P_j(t) \log_2 P_j(t). \tag{8}$$

The minimum value of entropy H = 0 corresponds to the degeneration of a stochastic system into a rigid determinate system. For open self-organizing systems the maximum $H_{max} = 1$ corresponds to a moment of bifurcation, when there is the destruction of pattern (microstructure) exhausting its dissipative abilities, and resulting in an emergence of new pattern at other hierarchical levels. Taking into account decomposition of entropy into a sum of two components and Eq. (1) for current balance, we have considered dynamics of the informational entropy flow in the LDZ of a system and obtained the analytical dependence on of the informational entropy flow on time in the following form:

$$H(t) = -\frac{\alpha}{(1+\alpha)\ln 2}\left\{\frac{1+\alpha e^{-\beta t}}{\alpha}\ln\left(\frac{1+\alpha e^{-\beta t}}{1+\alpha}\right) + \left(1 - e^{-\beta t}\right)\ln\left[\frac{\alpha\left(1 - e^{-\beta t}\right)}{1+\alpha}\right]\right\}. \tag{9}$$

The time courses of the entropy flow H(t) is shown in Figure 4. Analysis of Eq. (9) shows that in heavy mode of the LDZ being (at $\alpha>1$) at the time t_b, determining by Eq. (5), the maximum entropy flow is reached, $H(t_b)=1$. It can be shown that this moment corresponds to the condition of equal probabilities (maximum uncertainty) of keeping the LDZ in the down and up states $P_0(t_b) = P_1(t_b) = 0.5$. Note that this moment t_b corresponds to the critical point of maximum variation D_X^{max} of parameter X. That means, some fluctuations get amplified up to a macroscopic scale. In this way, fluctuations – environmental perturbations or eigenfluctuations – may drive the system into a completely new state and thus become the driving force of system development ("order through fluctuation" [9]). Instabilities at the same time can break symmetry, that is, bifurcations occur: the system may choose among two states, though determined by causality. The selection of the future path of development is unpredictable now [5]. However, at least we can predict the moment of maximum uncertainty and endeavor to take precautions against unfavorable paths of development.

After passing the system through the critical point, which is a stochastic analogue of the bifurcation point [8,12], the entropy flow decreases and, leaving the transient stage, stabilizes on the steady level H_{st}:

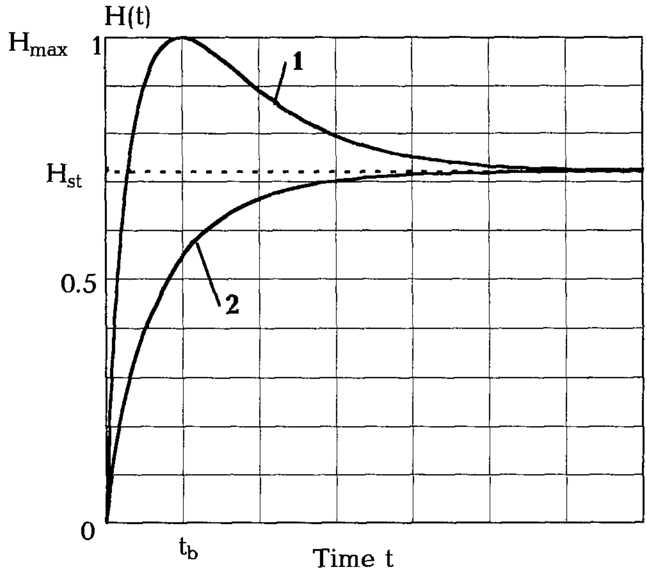

Figure 4. The time courses of the informational entropy flow H(t) for heavy (1) and light (2) modes of being (solid lines). Steady level H_{st} is denoted by the dashed line. The coordinates of the critical point are labeled as H_{max} and t_b.

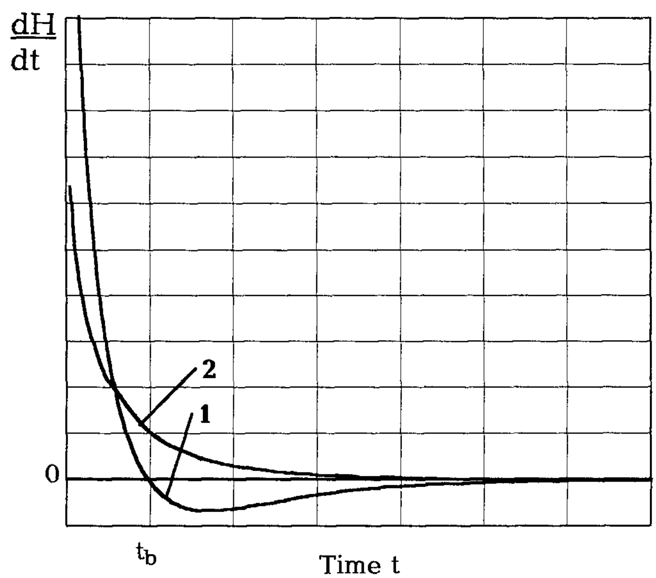

Figure 5. The time courses of the informational entropy flow rate dH/dt for heavy (1) and light (2) modes of being.

$$H_{st} = \ln\left[(1+\alpha)\Big/\alpha^{\frac{\alpha}{1+\alpha}}\right]/\ln 2 \,. \tag{10}$$

According to the traditional interpretation of entropy, it means that because of entropy outflow in the course of evolution, the disorder decreases. A system is structured in response to the heavy being mode by self-organization of more complicated and more advanced patterns. This is an attribute of the system's adaptation to the random process characterized by the regime parameter $\alpha>1$.

The light being mode of the LDZ when $\alpha<1$ (See line 2 in Figure 4) is characterized by absence of the stochastic analog of the bifurcation point and by stabilization of the entropy flow on the level H_{st} during the period of exit from the transient to stationary stage.

Special interest is attracted by dynamics of the entropy flow rate in the course of the system's evolution. The rate is defined as the derivation of the entropy flow function as:

$$\frac{dH}{dt} = -\frac{ve^{-\beta t}}{\ln 2}\ln\left[\frac{\alpha\left(1-e^{-\beta t}\right)}{1+\alpha e^{-\beta t}}\right]. \tag{11}$$

Plot of the entropy flow rate with time is shown in Figure 5. Analyzing the function (11) allows us to conclude that the response of a system to the heavy being mode ($\alpha>1$) by a rapid increase of the entropy flow takes place simultaneously with the reduction of the entropy flow rate to zero at the moment of time t_b. Hereafter the rate of entropy flow becomes negative, passes through a minimum, and aspires to zero, when the transient process approaches the steady (stable) stage.

4 Influence of the Variation of Conditions

Consider now the behavior of the LDZ with the variation of external and/or internal conditions of a system. The main point of interest of the foregoing analysis is the possibility of computing and forecasting a system response (namely the time course of the informational entropy) to a change of the being conditions. Denote values of the quantities, corresponding to a new set of conditions letters with an asterisk. The change of conditions may lead to both the modification of the regime parameter α^* and the probabilities P_0^* and P_1^*. Timing of time t^* started again at the moment of variation of the conditions. Solution of the differential Kolmogorov equations for the probabilities $P_0^*(t^*)$ and $P_1^*(t^*)$ was obtained [11].

An important role is played by analysis of the functions of entropy flow $H^*(t^*)$ and its rate dH^*/dt^* as a response of an open system to a sudden change of the external and/or internal conditions. Using Eq. (8), a mathematical expression for the time course of the informational entropy flow $H^*(t^*)$ under new conditions was obtained in following form:

$$\begin{aligned} H^*(t^*) = -\frac{1}{\ln 2(1+\alpha)(1+\alpha^*)}\Bigg\{&\left[(1+\alpha)+(\alpha^*-\alpha)e^{-\beta^* t^*}\right]\ln\frac{(1+\alpha)+(\alpha^*-\alpha)e^{-\beta^* t^*}}{(1+\alpha)(1+\alpha^*)}+ \\ &+\left[\alpha^*(1+\alpha)+(\alpha-\alpha^*)e^{-\beta^* t^*}\right]\ln\frac{\alpha^*(1+\alpha)+(\alpha-\alpha^*)e^{-\beta^* t^*}}{(1+\alpha)(1+\alpha^*)}\Bigg\}. \end{aligned} \tag{12}$$

A function of the informational entropy flow rate after a variation of conditions of the system existence can be expressed as:

$$\frac{dH^*}{dt^*}=\frac{\nu\mu^*-\nu^*\mu}{\beta\ln 2}e^{-\beta^*t^*}\ln\left[\frac{\nu^*\beta+(\nu\mu^*-\nu^*\mu)e^{-\beta^*t^*}}{\mu^*\beta+(\nu^*\mu-\nu\mu^*)e^{-\beta^*t^*}}\right]. \tag{13}$$

The initial rate of the entropy flow is equal to

$$\left.\frac{dH^*(t^*)}{dt^*}\right|_{t^*=0}=\frac{\nu\mu^*-\nu^*\mu}{\beta\ln 2}\ln\alpha\,. \tag{14}$$

It is evident that the obtained Eq. (12) to Eq. (14) depend on the combination of the previous and new being conditions.

Figure 6 shows the graphs of the informational entropy flow H* and its rate dH*/dt* for the case when being conditions become heavier ($\alpha<1$, $\alpha^*>1$). On the first time interval ($0<t<1.4$ sec) when $\alpha<1$, the LDZ exists in an easy being mode, so the entropy flow is stabilized at a level H_{st}, corresponding to this mode. At the time t = 1.4 sec, being conditions become heavier ($\alpha^*>1$). An open system responds to a strong change of conditions by a rapid increase of the entropy flow from the stationary level H_{st}, obtained under previous being conditions, to the maximum value $H^*(t_b^*) = 1$. At the time t_b^*, the rate of entropy flow sharply falls up to zero. The mathematical expression for the moment of time t_b^* was obtained in the following form:

$$t_b^*=-\frac{1}{\beta^*}\ln\frac{(\alpha^*-1)(\alpha+1)}{2(\alpha^*-\alpha)}. \tag{15}$$

One can note that it depends on a combination of the previous and new being conditions. In a time t_b^* after transition in a heavier being mode ($\alpha^*>1$), the LDZ passes across a bifurcation point. This point is associated with destruction of the pattern of the first hierarchical level, exhausting its dissipative possibilities, and emergence of a new appropriate pattern, corresponding to the changed being conditions. Leaving on the second level of hierarchy after the jump of development, the LDZ enters an evolutionary stage of development. There is the rather slow stabilization of the entropy flow during this stage at the expense of saturation by the information up to a level $I = 1- H_{st}^*$, which corresponds to a new mode of system existence. In other words, the LDZ adapts to new being conditions by perfection of structure. In this case, the entropy flow rate (See Fig. 6) gets a negative value, passes through a minimum and, remaining negative, aspires to zero, when the transient process reaches the stationary stage with a new steady level of the entropy flow H_{st}^*:

$$H_{st}^*=\ln\left[(1+\alpha^*)\Big/(\alpha^*)^{\frac{\alpha^*}{1+\alpha^*}}\right]/\ln 2\,, \tag{16}$$

adequate to new conditions.

In passage through the critical point at time t_b^* the variance D^*_X of the systems determining parameter X is maximum. The system is characterized at this stage by the highest degree of disordering, with the random fluctuations manifested on the macroscopic level. After passage through the critical point, the variance D^*_X is stabilized on a new stationary level corresponding to the changed being conditions.

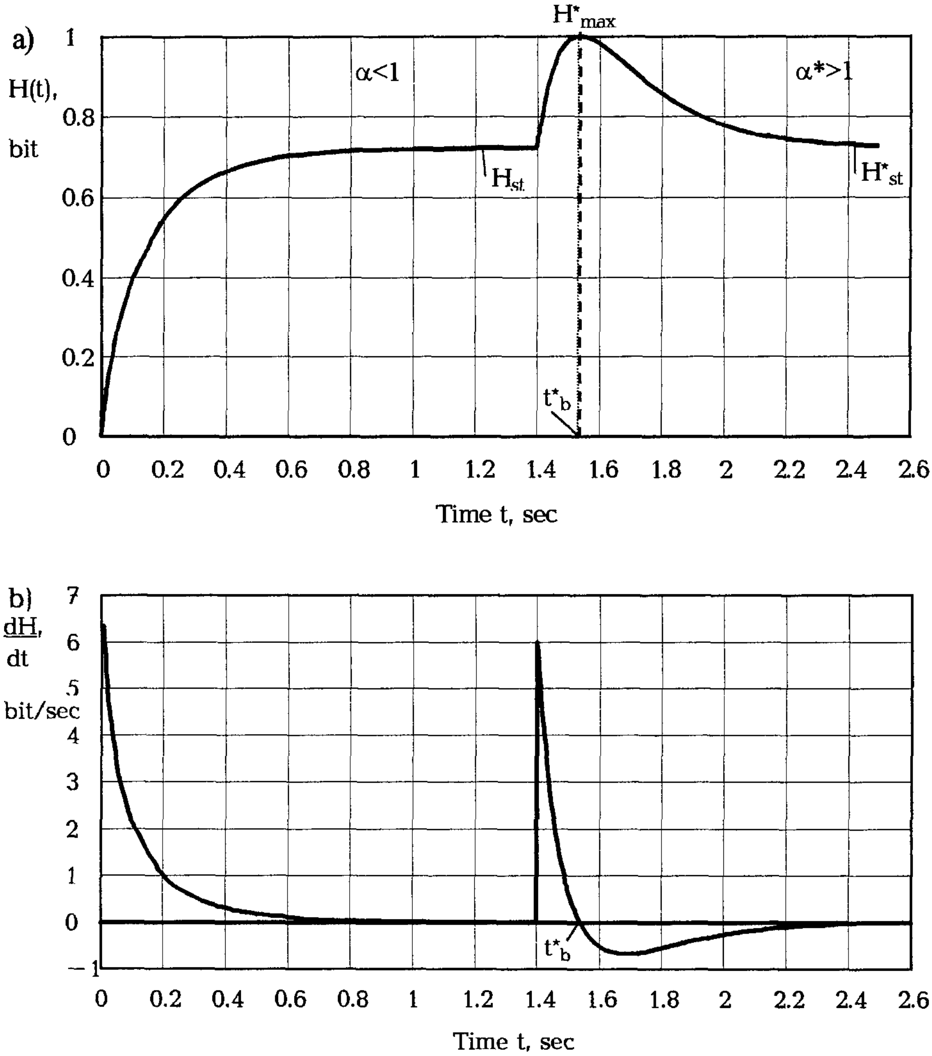

Figure 6. Response of a system to a change of the being conditions. The time courses of the informational entropy flow H(t) (a) and its rate dH/dt (b) for the case when mode of being becomes heavier ($\alpha<1$, $\alpha^*>1$). The coordinates of the critical point are labeled as H^*_{max} and t^*_b.

There is no place for more detailed examination of behavior in the course of time of the statistic properties of the systems determining parameter X after changing the being conditions. Let us note only, that there are possible both the cases of monotonous increase or decrease of the variance D^*_X and the cases of emerging the characteristic peak on a curve of variance D^*_X. The characteristic peak is similar to that shown in Figure 3 and corresponds to a critical point. Passing through such a typical peak and stabilizing the variance D^*_X on a new steady level D^*_{ST} confirm completion of the period of running in ("burn-in") of a system and its adaptation to new changed conditions. When testing the system, it is possible to measure and record the time history of the mean value and variance of determining parameter in the vicinity of some LDZs. We believe that on a basis of analysis of processes, occurring in the LDZ, it should be possible to speed up the reception of data concerning the termination of the transition to new state as well as adaptation of system to changed conditions. In Sec. 6 we shall consider the plots, representing the time evolution of the mean value and the variance for process of nucleation in model system involving multiple steady states [8,12].

An open system of any nature comes back in a steady stable state due to the inflow of information from the outside or/and redistribution of the informational entropy between hierarchical levels of the system [2].

After passage through the bifurcation point, the entropy flow decreases in accordance with an information accumulation; that means appropriate increase of an organization level during a system development. At each hierarchical level of a system's evolution at the end of self-organization process, when the "architecture" of the system was basically defined and becomes saturated by the information, the entropy curve is gradually straightened, displaying the transition of a system to the evolutionary stage of development. A growth in the degree of organization for any system has a limit, area of saturation, determined by the limited opportunities of an information accumulation in the given structure at a given hierarchical level.

Such a picture of temporal evolution of an open system with respect to variation of the being conditions agrees with the synergetic approach to processes of self-organization in nonequilibrium dissipative systems [1,4,8,9]. Obtained analytical dependencies reveal a quantitative ratio, reflecting the dynamics of the entropy flow and its rate, which shows the evolution of open systems in the course of its life cycle under variation of being conditions. The derived laws, in our opinion, are applicable for open nonequilibrium systems of various natures: technical, economic, biological, ecological, social, etc. The discussed model and obtained dependencies make it possible on a unified basis to describe the whole life cycle of a system, including passage across a sequence of bifurcation points ("jumps" of development) and evolutionary stages of development at each hierarchical level. Transition to a new level of development goes from disorder to order, through the phenomenon of instability in the bifurcation points, where a system has a number of options to diverge in several directions.

In the following, we shall give a few examples in order to elucidate the received results.

5 Example 1. Self-Organization during Elasto-Plastic Deformation of Metal

Here we consider an example of self-organization process during elasto-plastic deformation of metal in local zones of load-carrying structures. From the thermodynamic and synergetic points of view, a material undergoing plastic deformation is an open system brought far from equilibrium conditions [4,6,10]. In this case, the LDZ is represented by the zone of stress (strain) concentration. Let us accept as determining parameter X, limiting the lifetime of the load-carrying structure, stress intensity σ_i, determined from the distortion energy (Huber–Von Mises–Hencky) theory. It was assumed that transition from down state, corresponding to the elastic behavior of metal in the LDZ, in up (the plastic yielding state) is caused by such an external influence, exerted upon the system, under which the determining parameter exceeds a threshold level equal to the mean value of the yield strength σ_S, that is: $\sigma_i \geq \sigma_S$.

The main point of this example is to show how the random loading process exerted upon the load-carrying structure is linked with the structural response (namely the time course of entropy) to a change of the loading conditions. Let us accept the hypothesis that instantaneous values of the loading process have a normal distribution with the following statistical properties: mean value σ_m and variance D_σ of the stresses. Using Eq. (6), the relations that link the regime parameter α with these statistical properties and also with the threshold level (mean value of yield stress σ_S) were obtained in the following form:

$$\alpha = \left[\Phi\left(\frac{\sigma_S - \sigma_m}{D_\sigma}\right)\right]^{-1} - 1 \qquad \text{at } \sigma_m < \sigma_S, \tag{17}$$

$$\alpha = \left[1 - \Phi\left(\frac{\sigma_m - \sigma_S}{D_\sigma}\right)\right]^{-1} - 1 \qquad \text{at } \sigma_m > \sigma_S, \tag{18}$$

where

$$\Phi(Z) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z} \exp\left(\frac{-x^2}{2}\right) dx, Z = \frac{\sigma_S - \sigma_m}{D_\sigma}. \tag{19}$$

The dependence of α on σ_m and D_σ for low-carbon steel was computed from Eq. (17), (18) and plotted in Figure 7. We used this approach for a load-carrying welded structure, namely the pivoting section of a gondola car body. Examination of the time history of stress in elements of the gondola car, including directly the welded joints, carried out using the automated system for amplitude-spectral analysis, shows that the PDF of the instantaneous values of the random process is normal.

In the course of elasto-plastic deformation in metals, a number of dislocation patterns (microstructures) are formed. One after the other ball, cellular, persistent slip band, quasi-amorphous microstructures arise and are destroyed, consistently replacing each other on a background of existing grains' boundaries. Further increase of load results in formation of the crack origins in a quasi-amorphous zone and growth of their density. The spontaneous emergence of a quasi-amorphous microstructure corresponds to achievement of a maximum disorder in this local zone, at which point the thermodynamic entropy is maximum and equal to the enthalpy of melting. All these transitions are supervised by achievement of a maximum level of the entropy flow [4]. Under action of an energy flux, pumped up by the stochastic loading process in the LDZ, the deformation ability of metal at the lowest hierarchical structural level is exhausted. Getting through a critical point of bifurcation, metal passes to a higher level of the pattern hierarchy to microstructure, having the higher dissipative characteristic [4]. This transition between patterns on the microscopic level is reflected by the curves of the entropy flow and its rate, obtained before. Returning to Figure 6, note that at the first time stage ($0<t<1.4$ sec) the regime parameter α was determined by using Eq. (17) to be equal to 0.25. It corresponds to the vertical (gross) dynamic load of the gondola car. The value $\alpha^*=5$ corresponds to the total effect of the vertical and longitudinal inertial (in collision of cars) loads. That mode of the LDZ being matches the transition of metal in plastic state. In Figure 6, one can see that a load-carrying structure responds to the heavy conditions by a rapid increase of the entropy flow from the stationary level H_{st}, obtained under vertical load, to the maximum H^*_{max} at the time t_b^*. This critical point is associated with the destruction of the pattern exhausting its dissipative abilities, and the emergence of new microstructure at another hierarchical level corresponding to plastic state of the LDZ. The local zone becomes structured, responding to the heavy being mode by self-organization of more advanced patterns.

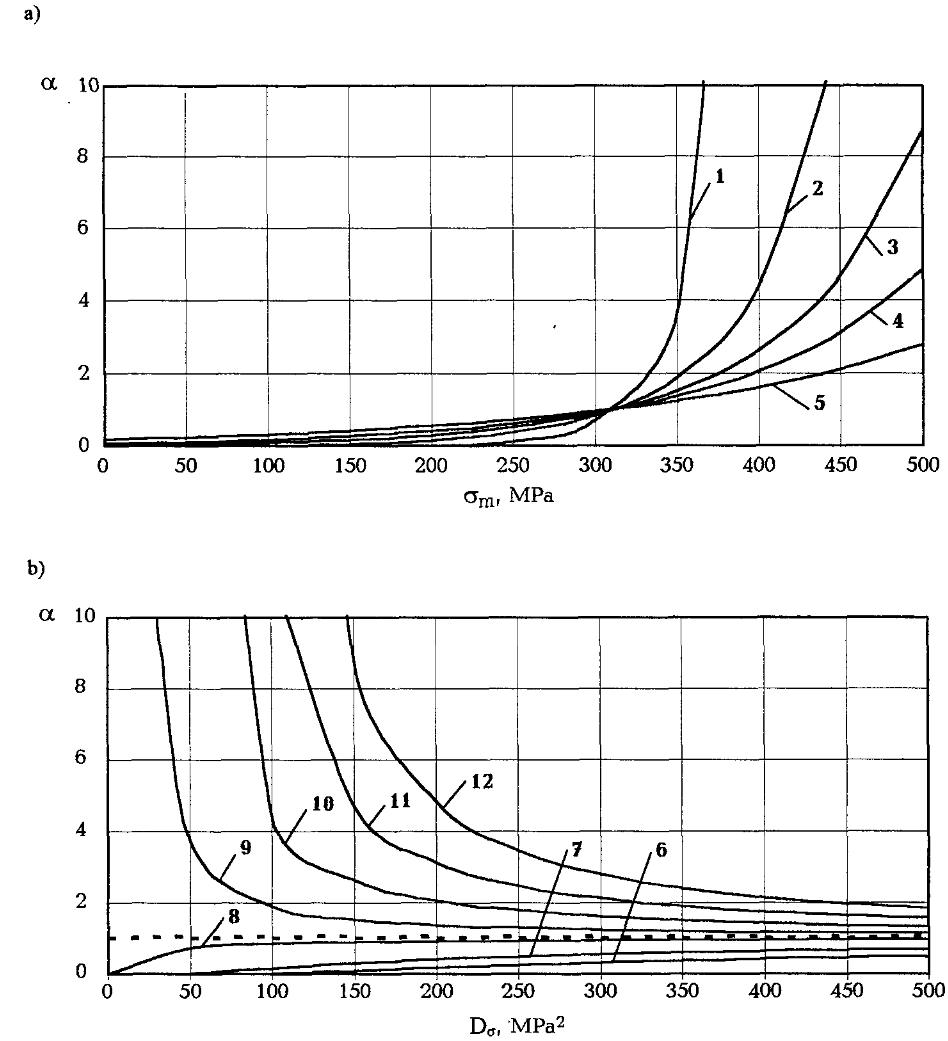

Figure 7. Change of the regime parameter α, as a function of the statistical properties (mean value σ_m (a) and variance D_σ (b)) of Gaussian random process of dynamic stresses: 1 – 5) D_σ is equal to 50, 100, 150, 200, 300 MPa^2 respectively; 6 – 12) σ_m is equal to 100, 200, 300, 350, 400, 450, 500 MPa respectively. Line $\alpha = 1$, corresponding to threshold level $\sigma_m = \sigma_S = 310$ MPa, is denoted by a dashed line.

6 Example 2. Nicolis and Prigogine's Model

A process of nucleation caused by formation of germs in model system involving multiple steady states is considered by Nicolis and Prigogine [8,12]. The plots, representing the time evolution of the average value and the variance for this numerical model, are indicated in Figure 8, which was adopted from [12].

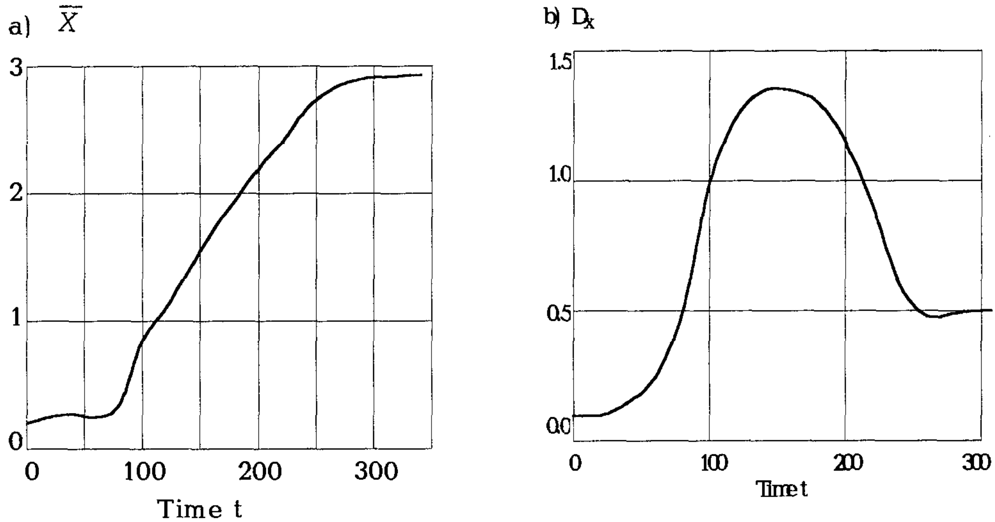

Figure 8. Evolution of the mean value $\overline{X}$ (a) and variance D_X (b) of fluctuations for the Nicolis-Prigogine's model. Adopted from [12].

We can see the process of the model system transition from initial state to another stable state corresponding to a higher level of mean value. During the process the mean value of determining parameter monotonously increases (See Fig. 8a). The variance begins to increase sharply as soon as sufficiently large new domain appears in the system through fluctuations. Appearance of the typical peak on the curve $D_X(t)$ and subsequent stabilization of the variance on a new steady level (See Fig. 8b) lead to a conclusion that the transition period is finished.

The plots of Figure 8 correspond to analytical dependencies, Eqs. (2), (3) of mean value $\overline{X}(t)$ and variance $D_X(t)$ of determining parameter X with time (See Figures 2 and 3). We believe that on a basis of the analysis of processes, occurring in the LDZ, it should be possible to speed up the reception of data concerning the termination of the transition as well as adaptation of system to new conditions.

7 Conclusions

The various kinds of open systems (technical, ecological, biological, socio-economic, etc.) respond to a strong change of being conditions in the same way: by steep growth of the entropy flow up to a maximum value at the critical point. According to the traditional interpretation of entropy, it means that the disordering and chaos in the system increase at this stage of its evolution. The critical point (being the stochastic analogue of a bifurcation point) associates with the self-organization process, that is the destruction of pattern of the previous hierarchical level, exhausting its possibilities, and resulting in the emergence of new more complicated and more advanced patterns, corresponding to the changed being conditions. An open system of any nature comes back to a steady stable state due to inflow of the information from the outside or/and redistribution of the informational entropy between the hierarchical levels of system.

Obtained mathematical expressions for the time course of the informational entropy flow make it possible to predict the moment that the critical point will be reached. That is the moment of maximum uncertainty, instability, and chaos in the system when small fluctuations become amplified up to a macroscopic scale. It may drive the open system into a completely new state and thus become the driving force of the system's development.

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